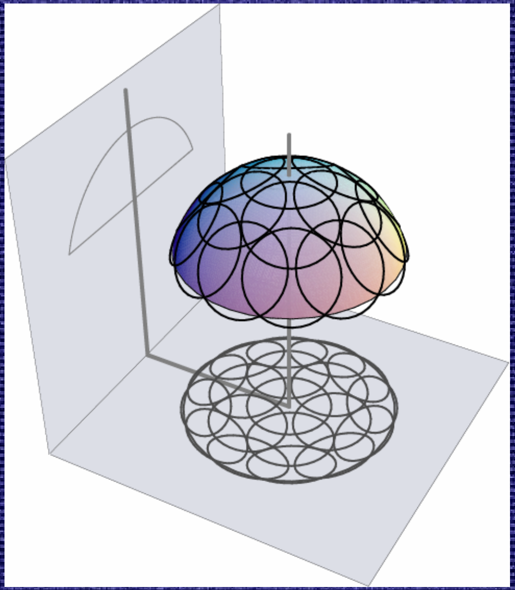

Advanced Metrology for Atypical Surfaces

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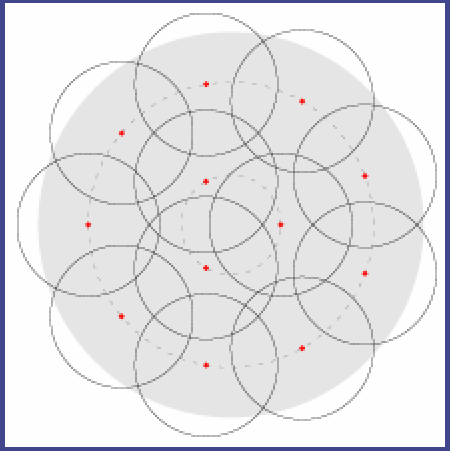
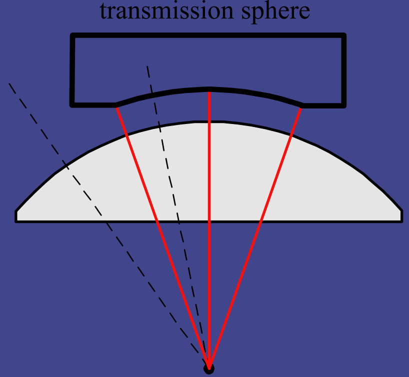
Advantages of subaperture stitching

- **Use of smaller interferometers**
  - Shorter air path (concaves) (use long radius diverger)
  - Smaller transmission optics (convex)
- **Higher lateral resolution**
  - Subaperture has the full interferometer resolution, so the stitched result can have more than that
- **Calibration of systematic errors**
  - Part motion allows reference wave and other calibrations
- **Avoid null optics for aspheric testing**
  - Again, the subaperture has the interferometer capability, so the stitched result can have more
  - Thus a high enough magnification with enough subapertures can non-null test an asphere

Stitching background and motivation

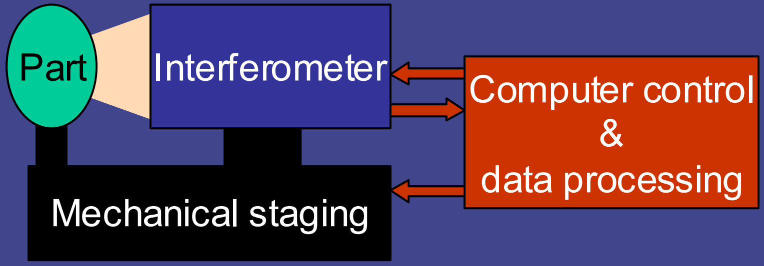
- **Background – subaperture stitching is not new**
  - Low-order polynomial fit to non-overlapped subapertures
  - Microscope pair-wise stitching
  - Zonal (annular subaperture) asphere testing
    - Translation along aspheric caustic to match local radius
  - Large, high-resolution plano optics
    - Simultaneous optimization of DC and tilt of all subapertures





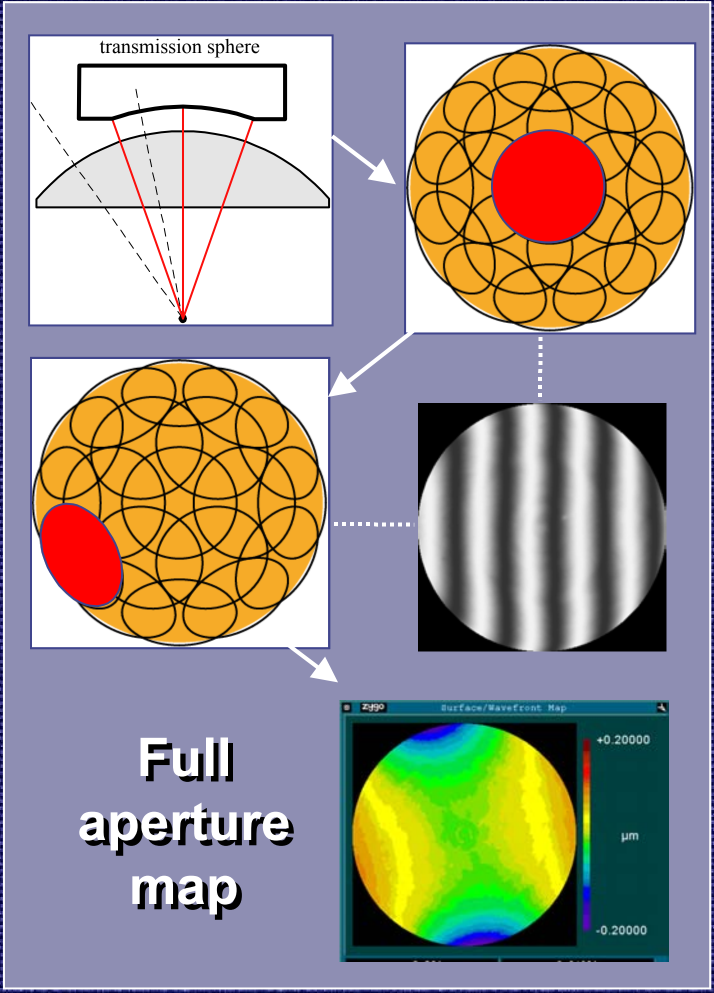
The SSI System

- **4” or 6” Zygo GPI Interferometer**
- **6-axis computer controlled workstation**
  - **Engineered in cooperation with Schneider Opticmachines**
- **QED patented techniques and advanced software**
  - Motion control
  - Interferometer control
  - Stitching algorithms
  - Automation



Innovative Metrology: SSI
Subaperture Stitching Interferometer

- **Full aperture measurement of large NA & CA parts**
- **Completely Automatic**
  - **Auto-Positioning, nulling, & radius testing**
- **Intuitive & Easy to Operate**
  - **Reference wave, distortion, pixel scale calibration**



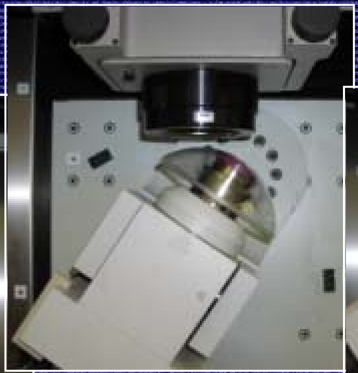
SSI measurement example

Aperture – 148.34 mm (5.84")
Radius – 82.55 mm (3.25")
CT – 3.04 mm (0.12")
Sag – 50.39 mm (1.984")

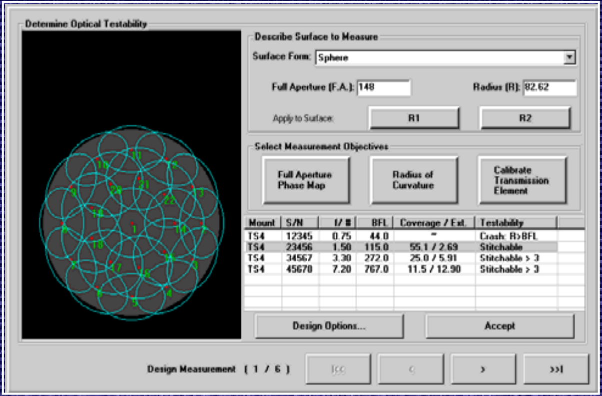
Objective - Zygo 4" f/1.5
Subaperture = 55.1 mm
Required 25 subapertures –
(4 center, 9 inner, 12 outer)

Center

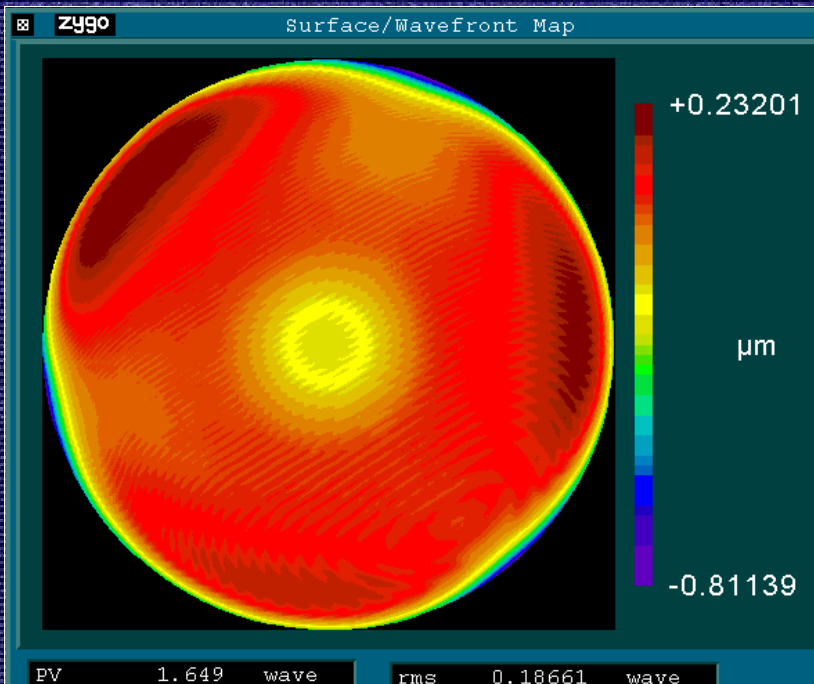
Inner Ring



Outer Ring

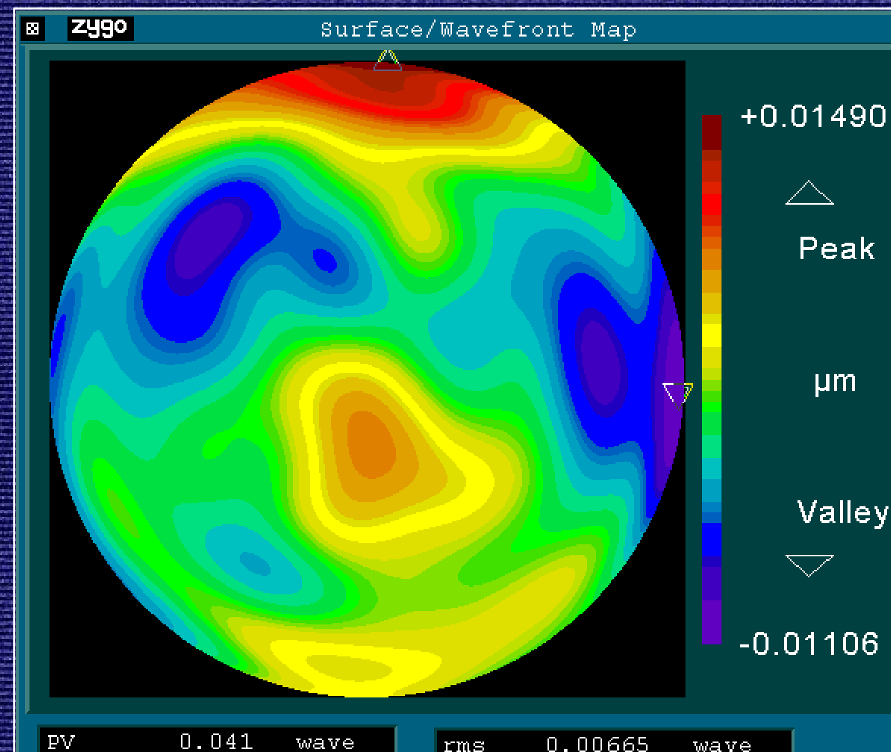


The Stitched Result



Radius: 82.6 mm
Surface:
PV – 1.649 λ (@ 633nm)
Rms – 0.187 λ (@ 633nm)
Total measurement time:
12 minutes!!

The Reference Wave Error



SSI measurement process

Specify surface to test

↓

Select transmission sphere and define lattice

↓

Locate central null

↓

Move to lattice position

↓

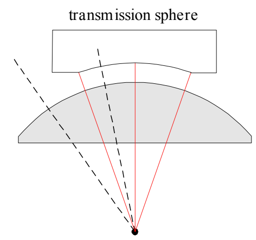
Auto-null

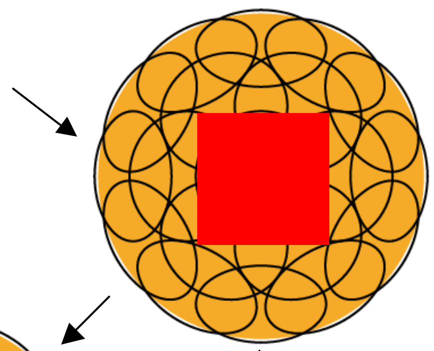
↓

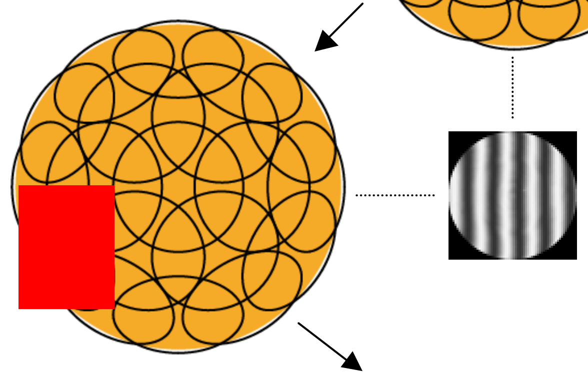
Measure

↓ (loop back to Move to lattice position)

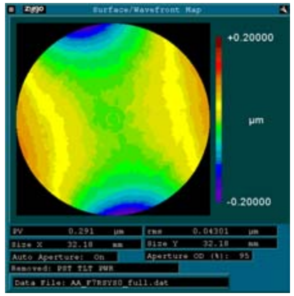
Stitch







Full-aperture map



Stitching algorithm

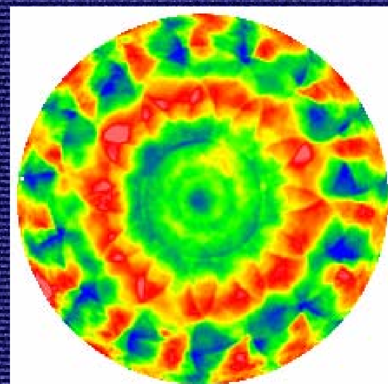
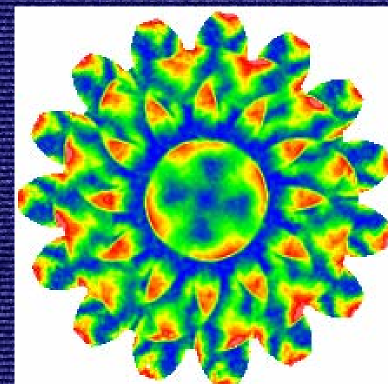
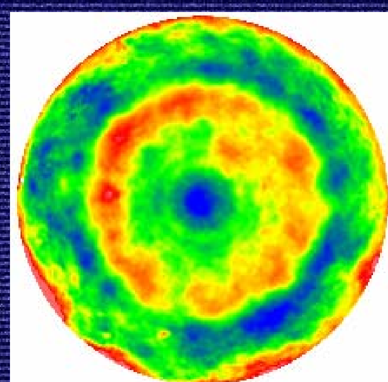
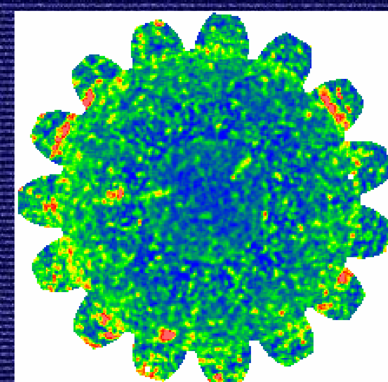
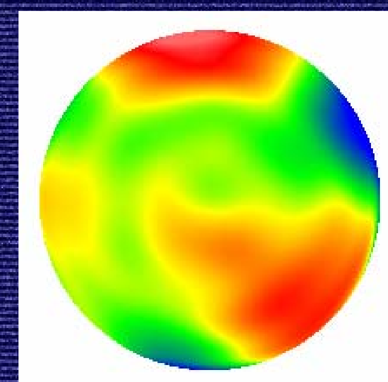
- Minimizes mismatch in overlap regions by adding an optimal amount of error compensation
  - Free compensators: vary in each subaperture
    - Traditional alignment errors: piston, tilt, power
    - But other errors can be included, e.g. translation, orientation
  - Interlocked compensators: same in each subaperture
    - Reference wave error (as a Zernike polynomial series)
    - Geometric distortions of viewing system
    - Does not require separate calibration procedure to determine and separate systematic errors from stitched results!

$$F_j(x,y) = f_j(x,y) + DC_j + Xtilt_j\, x + Ytilt_j\, y + Power_j\,(x^2 + y^2)$$

$$F_j(x,y) = f_j(x,y) + \left[\sum_k a_{jk}\, g_{jk}(x,y)\right] + \left[\sum_i \alpha_i\, G_{ji}(x,y)\right]$$

Example of stitching-computed reference wave

Reference wave compensation

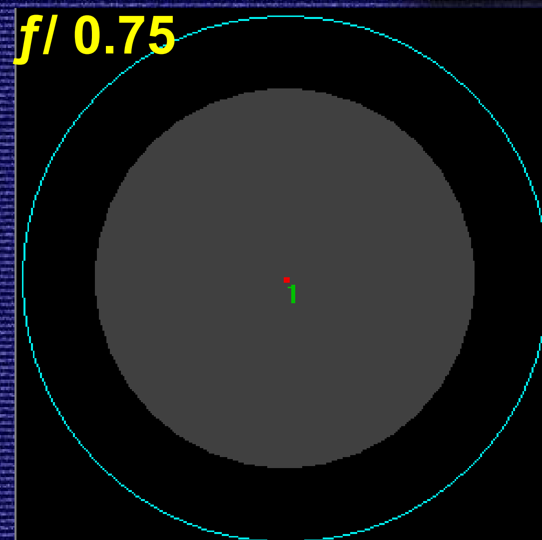
Reference wave compensation	full aperture	rms mismatch	reference wave
OFF	 PV 24.2 nm rms 3.71 nm	 PV 12.2 nm rms 4.56 nm	
ON	 PV 21.6 nm rms 3.10 nm	 PV 6.64 nm rms 1.05 nm	 PV 34.8 nm rms 4.34 nm

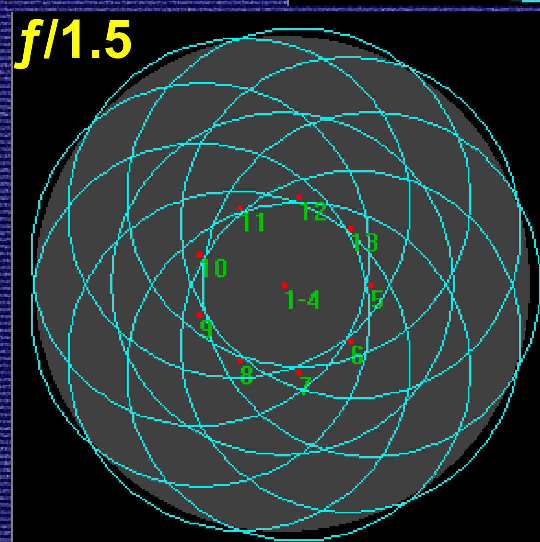
Metrology performance – stitched vs. full-aperture

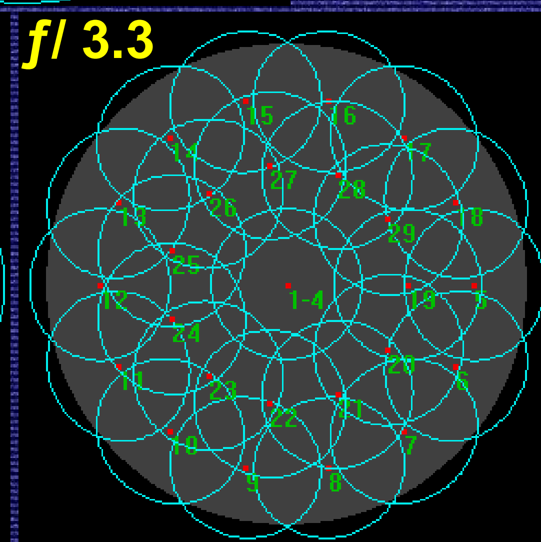
Comparison of stitched and full-aperture measurements

Ø: 38 mm R: 41.23 mm

R/ 1.09

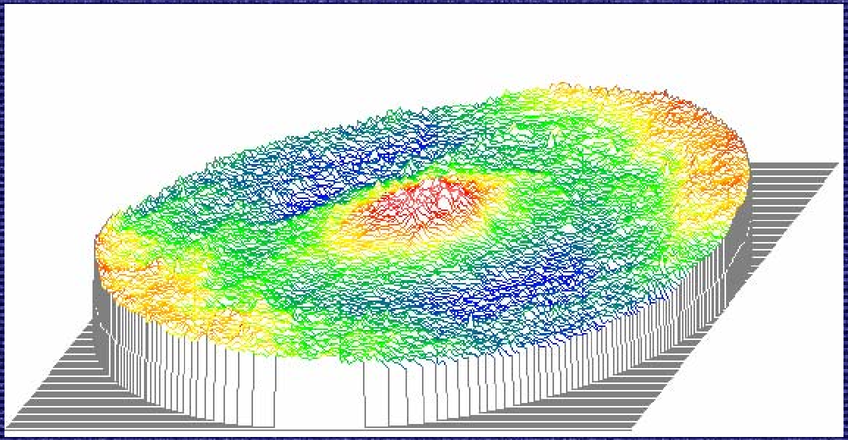






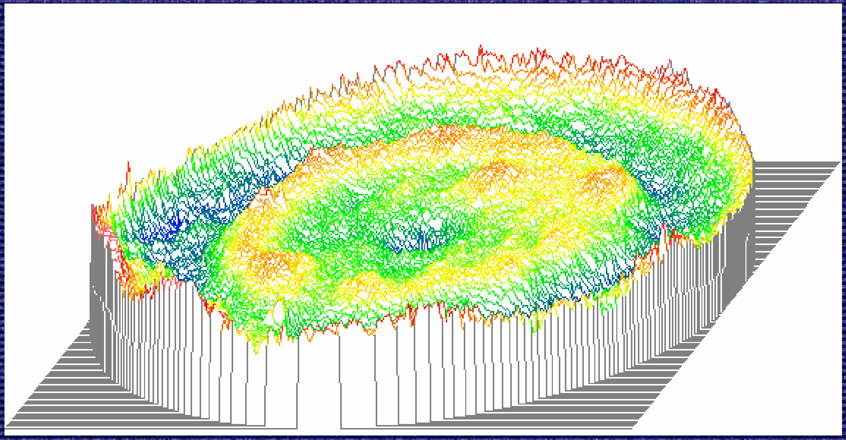
Full-aperture measurement using TS 4” f/ 0.75

reference wave (two-sphere calibrated)



PV: 14.7 nm rms 2.19 nm

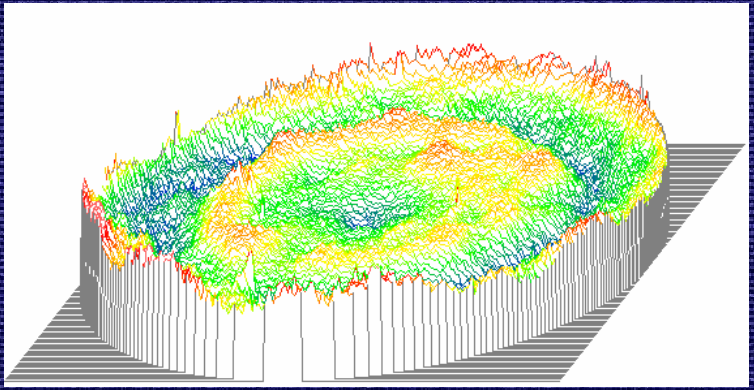
test surface



PV: 36.6 nm rms 3.72 nm

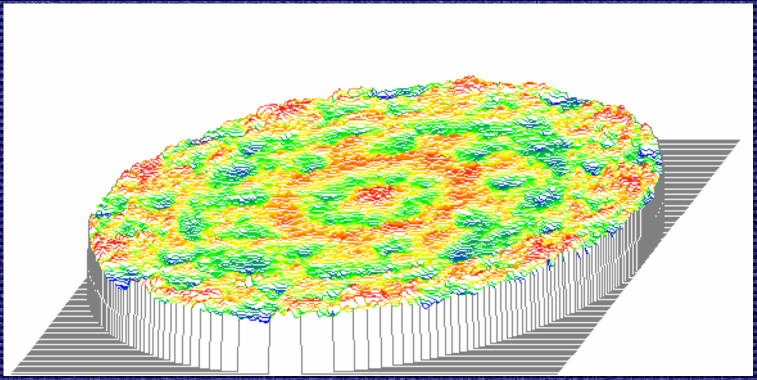
Stitched measurement using TS 4" f/ 1.5

Stitched test surface



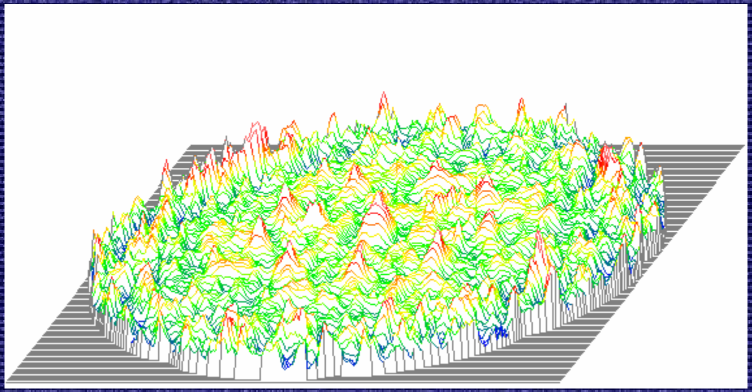
PV: 33.0 nm rms 3.64 nm

Difference from full aperture measurement



PV: 6.68 nm rms 0.66 nm

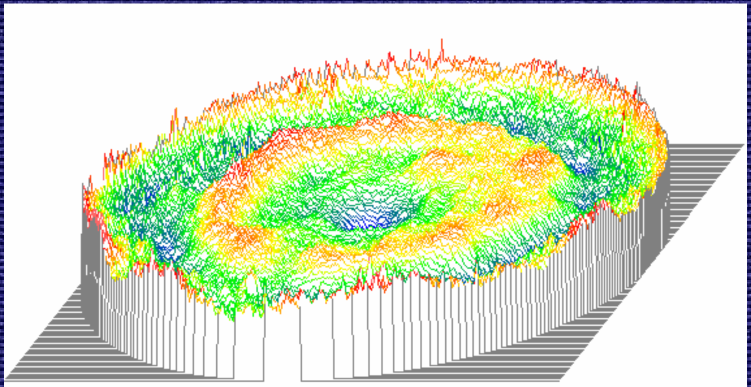
rms mismatch



PV: 3.46 nm rms 1.17 nm

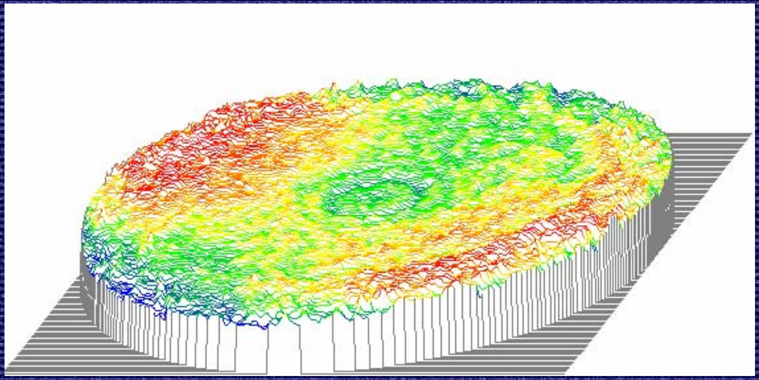
Stitched measurement using TS 4” f/ 3.3

Stitched test surface



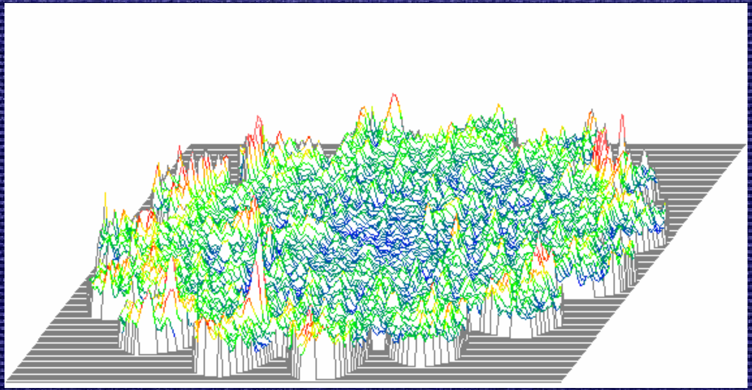
PV: 28.9 nm rms 3.18 nm

Difference from full aperture measurement



PV: 10.4 nm rms 1.32 nm

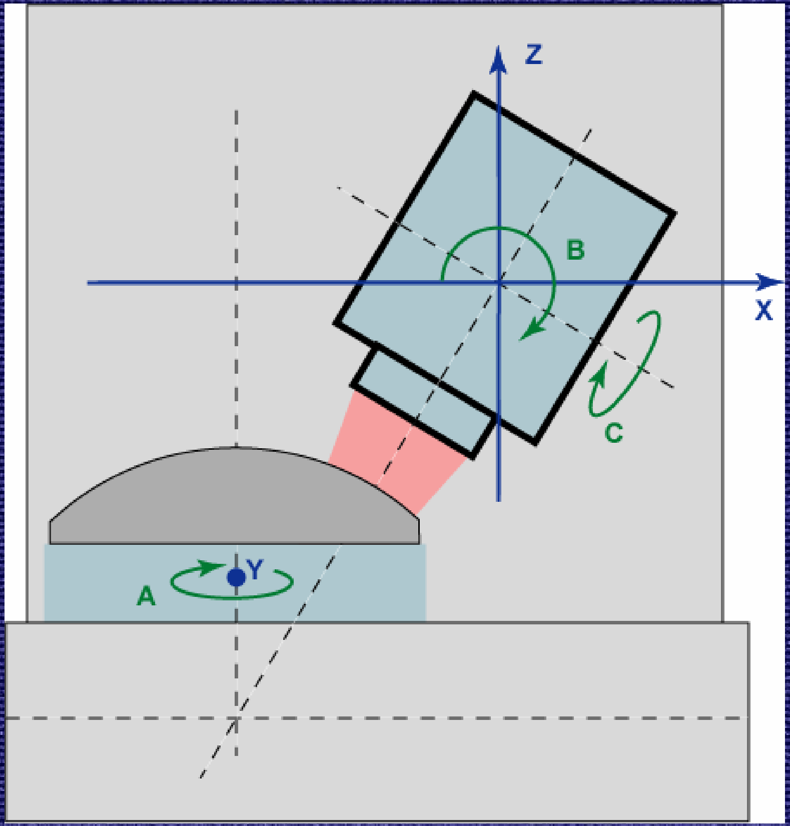
rms mismatch

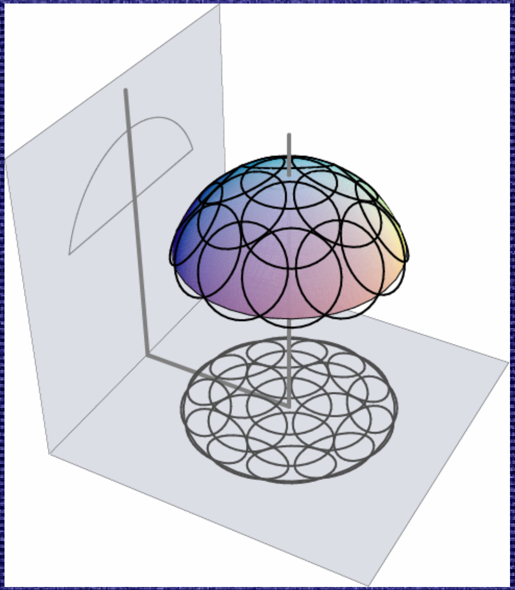


PV: 4.51 nm rms 1.05 nm

Stitching merits for large mirrors

- Boosted testable aperture sizes (i.e. cost-effective reference optics)
- Boosted testable aspheric departure (can alleviate need for nulls)
- Boosted accuracy (from thorough, automated calibration of reference wave, distortion, retrace, etc.)
- Boosted resolution
- Reduced non-common air path for long-radius concaves
- Dominant uncertainty well matched to adaptive mirrors





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